In the Supreme Court
OF THE
United States

OCTOBER TERM, 197_

No. 76-1425

MAURICE A. GARBELL, INC.,
and
GARBELL RESEARCH FOUNDATION
Petitioners,
v.
THE BOEING COMPANY,
Respondent.

and

MAURICE A. GARBELL, INC.,
and
GARBELL RESEARCH FOUNDATION
Petitioners,
v.
McDONNELL–DOUGLAS CORPORATION,
Respondent.

PETITION FOR WRIT OF CERTIORARI
to the United States Court of Appeals
for the Ninth Circuit

APPENDIX D
THE PATENT IN SUIT

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March 22, 1977.

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May 18, 1948 M. A. GARBELL 2,441,758

FLUID-FOIL LIFTING SURFACE

Filed July 16, 1946 3 Sheets-Sheet 1

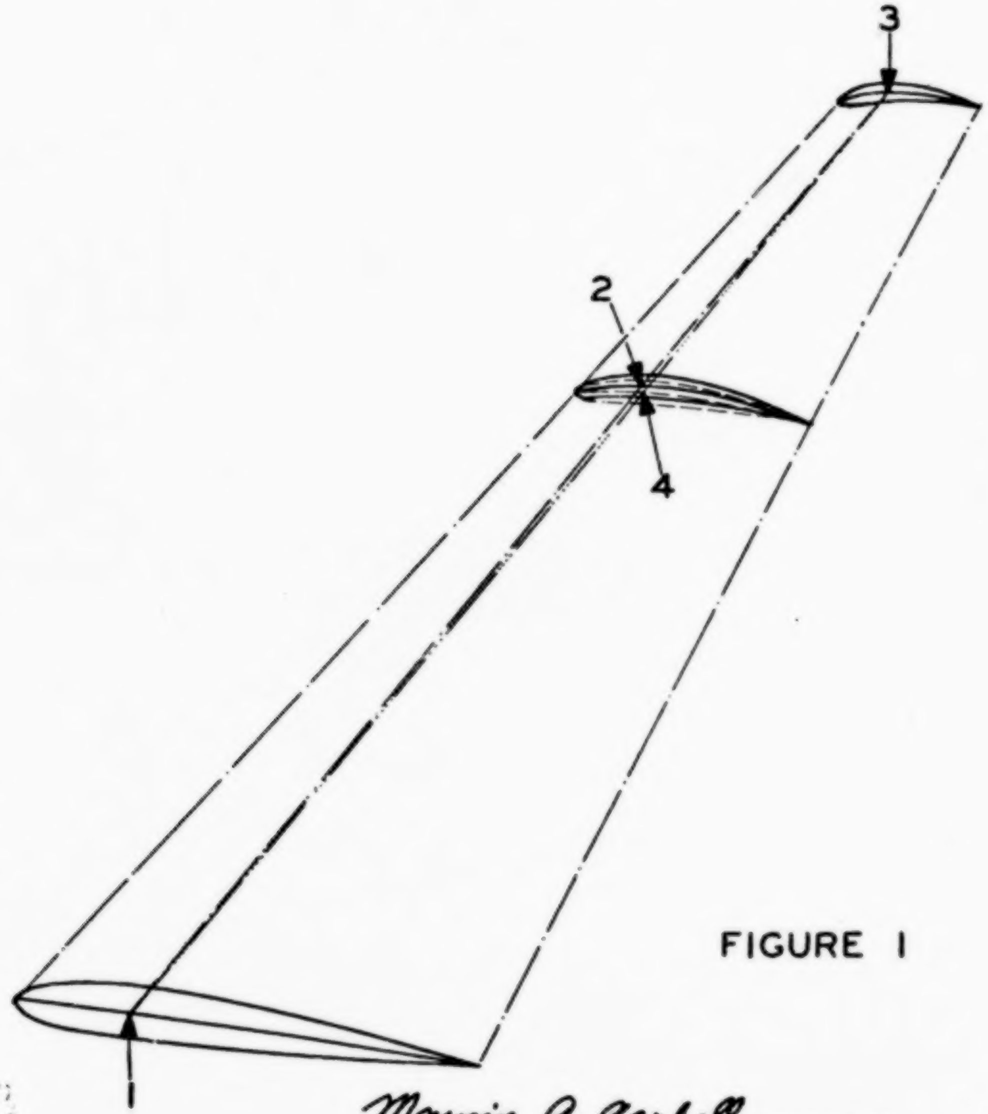


FIGURE I

Maurice A. Garbell INVENTOR.

BY Naylor and Lassagne
ATTORNEYS

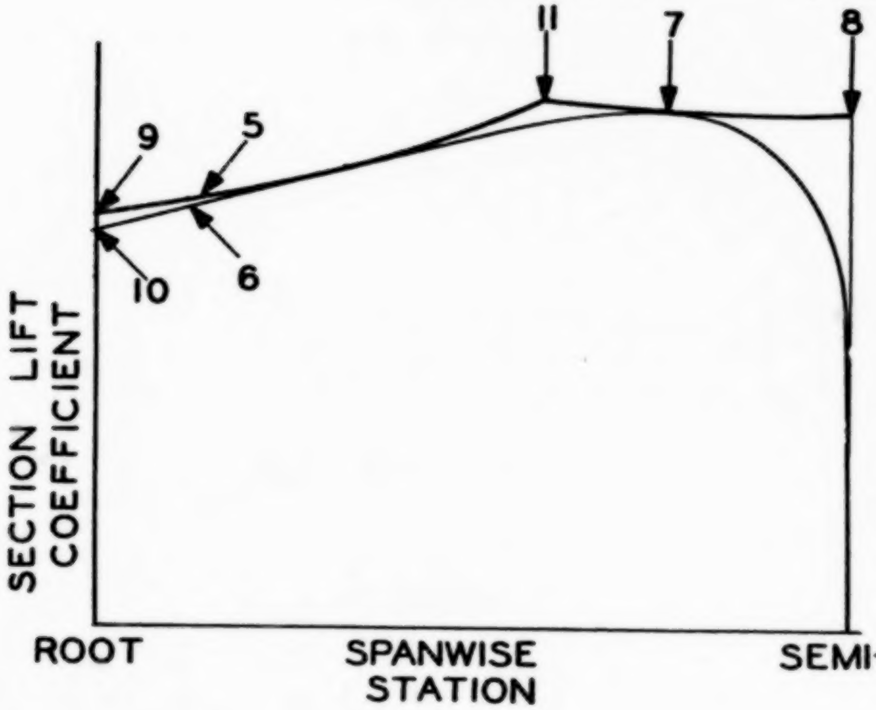
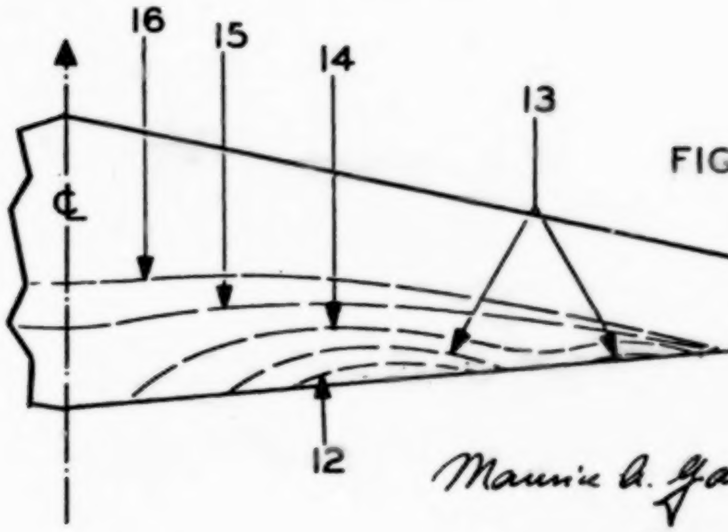


FIGURE 2

FIGURE 3



Maurice A. Garbell INVENTOR

BY Naylor and Lassagne

ATTORNEYS

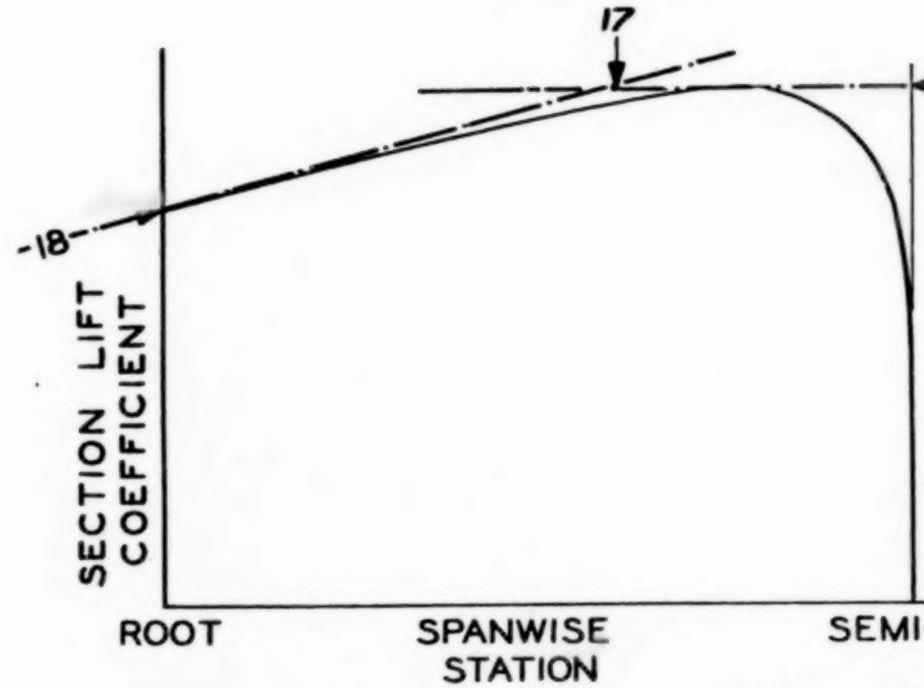


FIGURE 4

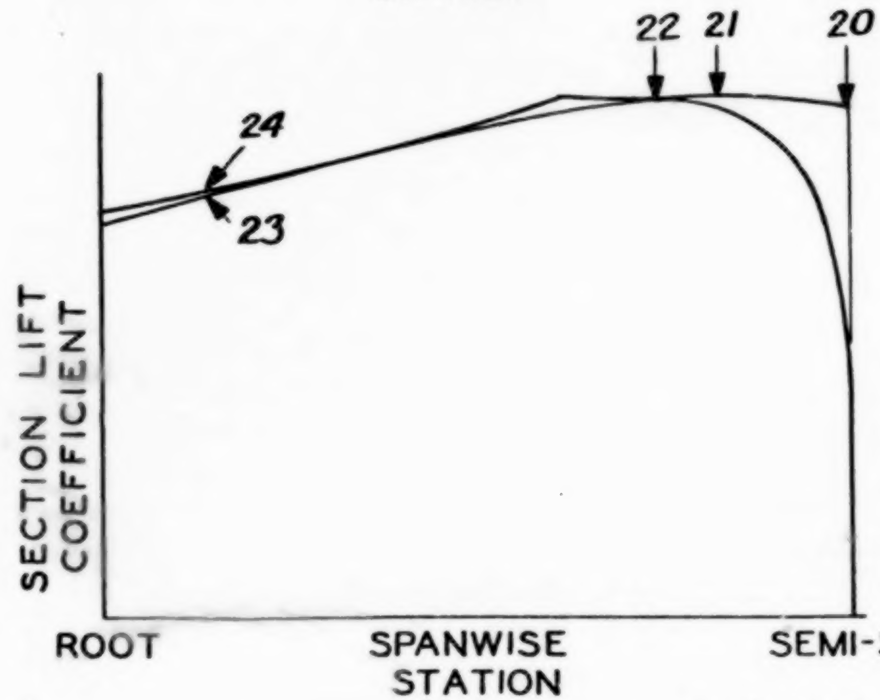


FIGURE 5

Maurice A. Garbell INVENTOR

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Patented May 18, 1948

2,441,758

UNITED STATES PATENT OFFICE

2,441,758

FLUID-FOIL LIFTING SURFACE

Maurice Adolph Garbell, San Francisco, Calif., assignor to Maurice A. Garbell, Inc., San Francisco, Calif., a corporation of California

Application July 16, 1946, Serial No. 683,815

15 Claims. (Cl. 244—35)

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This invention relates to the design and construction of surfaces to be driven through a fluid, intended to produce a useful force component perpendicular to the relative velocity of the fluid with respect to the surface, known in the art as "lift force," "side force," etc., and referred to hereinafter as "lift."

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In particular this invention relates to the design and construction of surfaces to be driven through the air, intended to produce an aerodynamic lift force perpendicular to the relative wind velocity with respect to the said surface, while minimizing the aerodynamic drag force parallel to the relative wind. In the art such surfaces are known as "wings," "fins," "blades," etc., and will be referred to hereinafter as "lifting surfaces." The closed curves resulting from intersections of the lifting surfaces with vertical planes parallel to the relative wind will be referred to hereinafter as "fluid-foil sections." The body to which the lifting surface is fastened will be referred to hereinafter as the "craft."

Figure 1 illustrates the preferred embodiment of this invention comprising a lifting surface designed and constructed according to the method outlined in the subject specification.

Figure 2 illustrates the spanwise distribution of actually prevailing section lift coefficients and the spanwise distribution of maximum attainable section lift coefficients on a typical lifting surface designed and constructed according to the subject method of this invention.

Figure 3 illustrates the typical inception and growth of the stall of a lifting surface designed and constructed according to the subject method of this invention.

Figure 4 illustrates the procedure employed in the finding of the optimum spanwise location of the third controlled fluid-foil section in a lifting surface designed and constructed according to the subject method of this invention.

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Figure 5 illustrates the spanwise distribution of actually prevailing section lift coefficients and the spanwise distribution of maximum attainable section lift coefficients on a typical lifting surface designed and constructed according to the subject method of this invention, the tip section of said lifting surface having a thickness ratio smaller than the optimum thickness ratio for absolutely maximum attainable section lift coefficient for the series of fluid-foils employed in the lifting surface.

The general object of this invention is the attainment of good stalling characteristics of lifting surfaces, said good stalling characteristics being achieved by the employment of three or

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more controlled fluid-foil sections **1**, **2**, and **3**, selected according to the method explained in the subject specification of this invention, wherein section **2**, representing the additional controlled sections interjacent between the root and the tip of the lifting surface, is at variance with the section **4** obtainable at the respective spanwise stations by means of straight-line fairing between the fluid-foil sections located at the root and the tip of the lifting surface.

Another object of this invention is the elimination of the violent rolling moments ordinarily produced by the unavoidable asymmetry of the stalling process, because the aforementioned method of fluid-foil selection suppresses the stall inception at the tip of the lifting surface and induces stall inception at a more inwardly located panel of the lifting surface, thus reducing the rolling moments acting on the craft for a

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given asymmetry of lift forces on the two stalled lifting surfaces.

Another object of this invention is the maintenance of adequate lateral-control effectiveness, together with the elimination of violent unstable control forces acting on control surfaces and devices attached to the trailing edge of the tip panel, during the critical stall-inception stage of the lifting surface, because the aforementioned method of fluid-foil selection induces stall inception at a more inwardly located panel of the lifting surface, so that the fluid flow over the tip panel and hence over the said control surfaces and devices remains smooth, thus maintaining effective lateral control as well as stable and smoothly varying control forces throughout the stall of the lifting surface.

Another object of this invention, through the employment of the aforementioned method of fluid-foil selection, is to reduce both the parasite drag and the induced drag of the unstalled lifting surface, and to shift the spanwise location of the "center of drag forces" of the stalled lifting surface inwardly so that the drag moment of the stalled lifting surface with respect to a vertical axis at or near the root is reduced to a value smaller than that of a lifting surface having a stall inception near the tip thereby reducing to a minimum the power required to maintain the rotation of partially or totally stalled lifting surfaces of the "rotating-wing" or "rotating-blade" type.

Additional objects of this invention will appear hereinafter.

In the art the achievement of the objects of this invention is recognized as one of the great steps in advancing safety and efficiency in air-

craft design. According to accident statistics of the Civil Aeronautics Boards and other aeronautical agencies most flying accidents, especially those accidents occurring while flying in proximity of the ground, during take-off, and when landing, are caused by the stall of the lifting surface, the severity of such accidents being attributable not so much to the loss of lift directly, as indirectly to the adverse longitudinal and lateral stability characteristics, to the loss of control effectiveness, and to the violent unstable control forces produced by the stall inception near the tip of the lifting surface.

An investigation of the fundamental reasons for unsatisfactory and hazardous stalling characteristics reveals that high plan-form taper and sweep-back of the lifting surface create three principal unfavorable effects resulting in a stall inception near the tip of the lifting surface: (1) a reduction of the scale factor known in the art as "Reynolds number" in direct proportion to the decrease of chord length from the root to the tip; according to well-known experimental evidence the maximum section lift coefficient attainable with a given fluid-foil section placed in the tip panel of the lifting surface is smaller than the maximum section lift coefficient that the same section would be capable of attaining were it placed in the root panel where the chord length and hence the Reynolds number are greater; (2) a deviation from the ideal "elliptical span-load distribution" tending to increase the lift coefficients prevailing over the tip sections and to reduce the lift coefficients prevailing over the root sections at any given total lift coefficient of the lifting surface; (3) an outwardly directed spanwise fluid cross-flow, especially on the suction side

of the lifting surface; this cross-flow at high lift coefficients of the lifting surface in an additional incentive for fluid-flow separation and stall near the tip of the lifting surface.

In the art, prior to this invention, it was customarily sought to counteract the aforementioned factors that contribute to the stall inception in the tip panel by resorting to the following measures: (a) effective washout, that is, washout of the zero-lift line of the fluid-foil section at the tip with respect to the zero-lift line of the root section, thus reducing the effective angle of attrack of the tip section below the effective angle of attack of the root section; (b) the employment of a fluid-foil section with a more highly cambered mean line at the tip of the lifting surface than at the root, in order to enable the tip section to attain higher maximum section lift coefficients.

These measures, however, have not been entirely successful in suppressing the stall inception near the tip of the lifting surface; the spanwise distribution of the actually prevailing section lift coefficients reaches a peak near the tip and therefore inevitably intersects the nearly linear spanwise distribution of maximum attainable section lift coefficients in this most critical portion of the lifting surface.

As a rule the resulting stall patterns remain unsatisfactory for all but the lowest of plan-form taper ratios, and may become dangerously critical for plan-form taper ratios in excess of 3:1 and for any highly swept-back lifting surfaces. The stall inception in the vicinity of the tip of the lifting surface and a comparatively slow inboardward progression of the stall with any further increase of the angle of attack of the lifting surface results in the most vicious type of tip stall, with

little or no stall warning, violent rolling moments, loss of lateral control, violent unstable control forces, and unstable nose-up pitching moments throughout the stall.

It was therefore customary in the art, prior to this invention, to employ as much washout and camber variations as was deemed permissible, and to transfer the further responsibility for the avoidance of the admittedly unsatisfactory stalling characteristics to the care of the pilots, or to warning signals actuated by the stalled fluid flow, or to a limitation of the elevator control travel to prevent the attainment of the high angles of attack at which stall occurs.

Techniques utilizing three controlled fluid-foil sections, in which the section at the semi-span center has either greater or smaller mean-line camber than the sections at the root and tip, have also failed to offer any substantial improvement of the dangerous tip-stall characteristics of highly tapered and/or swept-back lifting surfaces.

A preferred embodiment of this invention is described in the following specification; the broad scope of the invention is expressed in the claims concluding the instant application.

The invention consists of novel methods and combinations of methods described hereinafter, all of which contribute to produce a safe and efficient lifting surface.

Figure 1 illustrates the preferred embodiment of this invention, comprising a lifting surface with three or more "controlled" fluid-foil sections, in which the section with the least mean-line camber 1 is located at the root of the lifting surface, the section with the greatest mean-line camber 3 is located at the fluid-dynamically effective tip of the lifting surface (the actual tip fairing of the lifting surface may comprise a faired three-dimensional body without any identifiable mean-line camber, which is not of any consequence in the application of the subject invention), and one or more interjacent fluid-foil sections 2 are selected following the method outlined below, said interjacent fluid-foil sections having values of the mean-line camber at variance with the values 4 obtainable at the respective spanwise stations by means of straight-line fairing between the fluid-foil section located at the root and the fluid-foil section located at the tip of the lifting surface, provided that the respective values of the mean-line camber of the interjacent fluid-foil sections neither exceed the mean-line camber of the tip section nor fall below the mean-line camber of the root section. It shall be understood that the preceding considerations apply to all types of lifting surfaces regardless of the respective thickness ratios of the root and tip sections. It shall also be understood that additional considerations relative to the respective thickness ratios of the various controlled fluid-foil sections are presented herein for lifting surfaces wherein the thickness ratio of the root section is the greatest, and the thickness ratio of the tip section is the smallest, respectively, of any fluid-foil section employed in the lifting surface.

Figure 2 illustrates the preferred manner in which this invention, through the employment of the aforementioned method of fluid-foil selection, achieves the establishment of a curvilinear polygon 5 describing the spanwise distribution of maximum attainable section lift coefficients, said curvilinear polygon being so shaped that it envelops closely the curve 6 describing the

spanwise distribution of the actually prevailing section lift coefficients, except that beyond the spanwise point 7 at which the highest actually prevailing section lift coefficient occurs the maximum attainable section lift coefficient exceeds substantially the actually prevailing section lift coefficient, so that the stall inception occurs near mid-semispan, spreads more prevalently inboardward and to a smaller extent outboardward, and does not involve the extreme tip of the lifting surface prior to the breakdown of the fluid flow over the entire remaining lifting surface.

As used herein the curvilinear polygon 5 describing the spanwise distribution of maximum attainable section lift coefficients is established by the respective values of the maximum attainable lift coefficients of the root section 9, the tip section 8, and the third or additional control section 11, and by the respective maximum attainable lift coefficients 5 of the sections obtained by conventional fairing between each pair of controlled sections 9—11, 11—8, etc.

The curve 6 describing the spanwise distribution of the actually prevailing section lift coefficients at the maximum lift coefficient of the lifting surface is obtained by conventional methods of experimentally verified calculation for the desired lifting surface, taking into consideration the plan-form, effective aerodynamic washout, section lift-curve-slope characteristics, etc.

The term "envelopment" as used herein signifies the establishment of curvilinear polygon 5 on the convex side of curve 6, wherein each individual branch 9—11, 11—8, and so forth of the curvilinear polygon 5 is tangent or nearly tangent to curve 6.

Figure 3 illustrates the stall progression re-

sulting from the employment of the subject method of this invention. The curves 12, 13, 14, 15, and 16 indicate, in their orderly progression, the extent of the stalled lifting-surface area at angles of attack greater than the angle of attack at which stall inception 12 first occurs. This spanwise far-reaching yet gradual spread of the stalled area prevents the formation of a deep local stall in a chordwise or depthwise sense at any one spanwise station. Steep spanwise pressure differences between unstalled sections and stalled sections, and hence deep spanwise cross-flows, are thereby effectively prevented.

The prevalently inboardward development of the stalled area not only produces the desired timely stall warning in the form of a gentle tail shake at a speed slightly in excess of stalling speed, but serves also to reduce the downwash of the fluid flow aft of the lifting surface in the space usually occupied by the horizontal stabilizer, so that an upwardly directed lift-force increment is made to act on the horizontal stabilizer, thereby imposing a nose-down pitching moment on the craft that induces the craft to return to smaller angles of attack and brings to a halt any further progress and intensification of the stalling process by precluding any increase in angle of attack beyond the stalling angle.

The following specification outlines the method employed in the design of the subject lifting surface of this invention, whereby to select the most opportune values of fluid-foil section mean-line camber and fluid-foil section thickness ratio required to achieve the objects of the instant invention:

To apply the subject method of this invention it is actually necessary to know only the plan form of the lifting surface and the desired stall

pattern. Inasmuch as practical considerations other than those pertaining solely to the control of the stalling characteristics ordinarily predetermine certain design parameters of the lifting surface, preferred embodiments of the subject method of this invention are hereinafter explained for two typical combinations of predetermined basic design parameters:

In the first typical configuration the following design parameters, for example, are assumed to be given a priori: (*a*) the plan form of the lifting surface, based on structural and practical design considerations; (*b*) the series of fluid-foil sections to be employed, based on high-speed and other performance requirements; (*c*) the maximum permissible effective aerodynamic washout, based on drag considerations and structural bending-moment limitations; (*d*) the thickness ratio of the fluid-foil section at the root, based on the critical-Mach-Number requirements and structural weight considerations; (*e*) the thickness ratio of the fluid-foil section at the tip, based on practical space requirements for control-surface balances, etc.; (*f*) the mean-line camber of the fluid-foil section at the tip, based on the requirement of adequate torsional lifting-surface stiffness at high speed.

The subject method of this invention is employed firstly to design the lifting surface without any effective aerodynamic washout, that is, with the three or more controlled fluid-foil sections placed at such an angle of incidence with respect to the reference chord plane of the lifting surface that the said fluid-foil sections operate at their respective zero-lift angles of attack when the entire lifting surface operates at its angle of attack for zero overall lift.

Based on fundamental experimental wind-tunnel data available for the pre-selected series of fluid-foil sections, graphs are plotted showing the variation in the maximum attainable section lift coefficient versus the mean-line camber, thickness ratio, and Reynolds number, respectively; similar graphs are plotted showing the variation in the section zero-lift angle of attack versus the mean-line camber, thickness ratio, and Reynolds number, respectively.

The approximate maximum attainable lift coefficient of the entire lifting surface for appropriate values of the Reynolds number is estimated, for example, by dividing the maximum attainable section lift coefficient of the tip section **8** (obtained from the aforementioned wind-tunnel data) by the highest spanwise value of the "additional section lift coefficient

$$C_{l_{a_1}}$$

(as defined in Army-Navy-Commerce ANC-1(1) entitled "Spanwise Air-Load Distribution"), as follows:

$$C_{L_{max}} = \frac{C_{l_{max\ tip}}}{C_{{l_{a_1}}_{highest}}}$$

this equation yields that lift coefficient of the entire lifting surface at which the most highly loaded section **7** carries a section lift coefficient substantially equal to the maximum attainable section lift coefficient **8** of the fluid-foil section employed at the tip.

The spanwise distribution **6** of the actually prevailing section lift coefficients is then calculated for the maximum lift coefficient $C_{L_{max}}$ of the entire lifting surface, following one of the conventional calculation methods, for example,

the method outlined in the Army-Navy-Commerce Manual ANC-1(1).

For the Reynolds number and the pre-selected thickness ratio of the root section, the required value of mean-line camber is determined from the graph showing the experimentally determined variation of the maximum attainable section lift coefficient with varying mean-line camber, selecting that value of the mean-line camber that produces a maximum attainable section lift coefficient 9 equal to or slightly superior to the section lift coefficient 10 actually prevailing over the root section.

For the spanwise location of the third and additional controlled sections 2 and 11, the subject method of this invention utilizes preferringly locations between the spanwise point of the highest actually prevailing section lift coefficient 7 and the root 10 of the lifting surface; the most efficient interval wherein to locate the third controlled section lies between the spanwise point of the highest actually prevailing section lift coefficient 7 and the spanwise point located twice as distantly from the tip as point 7, with a preferable optimum at the point 17, where the tangent to the inboard portion of the curve of spanwise distribution of the actually prevailing section lift coefficients 18 intersects the horizontal tangent 19 to the same curve, as shown in Figure 4.

It will be understood, however, that inescapable practical design considerations may require that the additional controlled sections 2 and 11 be placed at spanwise stations located inside power plant nacelles or at those spanwise stations where the lifting surface is mechanically jointed for sudden changes in plan-form taper, or sweepback, as is the case in craft with removable or foldable outboard panels.

The Reynolds number is calculated for the third controlled section; the thickness ratio obtainable at the third section by straight-line interpolation between the root section and the tip section is also determined. For the Reynolds number and thickness ratio thus determined, the required value of mean-line camber is found from the graph showing the experimentally determined variation of the maximum attainable section lift coefficient with varying mean-line camber, selecting that value of the mean-line camber which produces a maximum attainable section lift coefficient 11 and 17 equal to or slightly superior to the highest actually prevailing section lift coefficient 7.

From the foregoing, it will be readily seen that the lifting surface obtained by the invention, and defined by the curvilinear polygon 5, embodies the combination of an airfoil section 1 or 9 having the smallest mean line camber at the root, an airfoil section 3 or 8 having the greatest mean line camber at the tip, and one or more interjacent controlled sections 2 or 11, having values of the mean line camber at variance with the values 4 obtainable at the respective spanwise stations by means of straight line fairing between the root section and the tip section.

If the required maximum attainable section lift coefficient for the interjacent section 11 cannot be obtained with a mean-line camber not exceeding the mean-line camber of the tip section, a value equal to or slightly less than the mean-line camber of the tip section is selected. The maximum attainable section lift coefficient of the interjacent section is then increased by changing the section thickness ratio in the proper sense, usually downward, until either the required

maximum attainable section lift coefficient 11 is obtained, or until structural considerations interfere with the continuance of this procedure. If this process does not offer a conclusive result, which is rare, a small amount of effective aerodynamic washout is then introduced, ½° to 1° in each step of the application of the method, wherein the total effective aerodynamic washout is distributed in appropriate fashion between the controlled sections and where the total washout is less than the maximum permissible washout as defined in the aforelisted initial design assumptions. The entire heretofore specified procedure including the establishment of a curve 6 conforming to the washout chosen, is then repeated for the selected amount of effective aerodynamic washout, until the desired results as illustrated in Figures 2 and 3 are attained.

A typical example of the application of the principles of this invention to one well-known type of lifting surface is as follows: Here we assume a planform taper ratio of three to one, an aspect ratio of ten, a total effective aerodynamic washout of zero degrees, a constant section thickness ratio of twelve per cent along the entire semi-span, the utilization of "64—" series NACA "low-drag" fluid-foil sections, a mean-line camber of the root section 1 characterized by an "ideal lift coefficient" C_{l_i} equal to 0.1, and a mean-line camber of the tip section 3 characterized by an "ideal lift coefficient" C_{l_i} equal to 0.45. The term "ideal lift coefficient" is to be interpreted as defined by the National Advisory Committee for Aeronautics nomenclature and is herein used as a parameter characteristic of the mean line camber of a fluid foil section. Calculations based on conventional methods will indicate that a lifting surface having the above

general design parameters will experience, at its maximum resultant lift coefficient, a distribution of section lift coefficients as illustrated in curve 6.

Following the procedures hereinbefore described, we achieve in the above-outlined construction the desirable stalling characteristics taught by this invention through the use of a controlled fluid-foil section 2 or 11 at a station approximately 55 per cent of the semi-span from the root and with an effective aerodynamic washout of zero degrees with respect to the root section, wherein the mean-line camber of the interjacent controlled section 2 or 11 is characterized by an "ideal lift coefficient" C_{l_i} equal to 0.35. In this structural example the mean-line camber of the interjacent controlled section 2 or 11 is greater than that of the root section 1 or 9, smaller than that of the tip section 3 or 8, and greater than that of the interpolated section 4 obtainable at the 55-per-cent semi-span station by means of straight-line fairing between sections 1 and 3, and which accomplishes the envelopment of curve 6 by the curvilinear polygon 5.

In another typical example, a lifting surface is assumed as having substantially identical basic design geometry as the preceding example, except for a structurally desirable root thickness ratio of twenty-three per cent, a tip thickness ratio of seven per cent, a total effective aerodynamic washout of one degree, and a thickness ratio of fifteen per cent at an interjacent station located at approximately 60 per cent of the semi-span.

Again following the procedure of this invention we achieve in the abovedescribed construction the desirable stalling characteristics taught

by this invention through the use of a controlled fluid-foil section 2 or 11 at the station located approximately 60 per cent of the semi-span from the root and with an effective aerodynamic wash-out of 0.5 degree with respect to the root section, wherein the mean-line camber of the interjacent controlled section 2 or 11 is characterized by an "ideal lift coefficient" C_{l_i} equal to 0.12. In this structural example the mean-line camber of the interjacent controlled section 2 or 11 is greater than that of the root section 1 or 9, smaller than that of the tip section 3 or 8, and smaller than that of the interpolated section 4 obtainable at the 60-per-cent semi-span station by means of straight-line fairing between sections 1 and 3, and which accomplishes the envelopment of curve 6 by the curvilinear polygon 5.

(2) The second typical configuration differs from the first in that the thickness ratio of the tip section 3 is not predetermined. Hence, the following design parameters are assumed to be given a priori: (*a*) the plan form of the lifting surface; (*b*) the series of fluid-foil sections to be employed and their fluid-dynamic characteristics; (*c*) the maximum permissible effective aerodynamic washout; (*d*) the thickness ratio of the fluid-foil section at the root; (*e*) the mean-line camber of the fluid-foil section at the tip.

In this case where the thickness ratio of the tip section is not predetermined but is left to the judgment of the fluid-dynamical design engineer, the subject method of this invention employs to good advantage a peculiarity observed in the variation of the maximum attainable section lift coefficient with varying section thickness ratio. Most series of related fluid-foil sections reach their absolutely highest maximum

section lift coefficient (for a given mean-line camber and Reynolds number) at a certain experimentally determined thickness ratio, usually between 12% and 16%. Sections with thickness ratios greater or smaller than optimum attain less than the absolutely maximum section lift coefficient. If, as illustrated in Figure 5, a thickness ratio smaller than optimum is used at the tip 20 of a lifting surface, where the actually prevailing section lift coefficients are greatly below their highest spanwise value 22, the fluid-foil section with the optimum thickness ratio can be located at a spanwise station 21 a small distance inboard of the tip, near the spanwise station 22 at which the highest actually prevailing section lift coefficient is encountered. Here it will be understood that the mean-line camber of the interjacent controlled section 2 may be greater or smaller than that of the aforementioned section 4, depending on the range of section thickness ratios encountered between the root and the tip of the lifting surface.

In this case the subject method of this invention is modified to the extent that, in calculating the spanwise distribution of the actually prevailing section lift coefficients 23, the maximum lift coefficient $C_{L_{max}}$ of the entire lifting surface shall be determined not on the basis of the maximum attainable section lift coefficient of the tip section, but on the basis of the absolutely maximum attainable section lift coefficient 21, that is, for the section of optimum thickness ratio, as follows:

$$C_{L_{max}} = \frac{C_{l_{max\ abs.}}}{C_{l_{a_{l_{highest}}}}}$$

The thickness ratio of the fluid-foil section at the

tip of the lifting surface is then so chosen that the section 21 with optimum thickness ratio for absolutely maximum attainable section lift coefficient lies between the spanwise station of highest actually prevailing section lift coefficient 22 and the tip 20, unless structural and other design criteria interfere by establishing a minimum section thickness ratio.

If the designer intends to achieve positive stall inception in a certain spanwise panel of the lifting surface, the subject method of this invention provides that in either of the aforedescribed design procedures the mean-line camber and thickness ratios, as well as the spanwise location, of the sections comprised within or adjacent to the panel for which stall inception is desired be so selected that within the "stall inception panel" the curve of maximum attainable section lift coefficients lies slightly below the curve of actually prevailing section lift coefficients, without modifying the aforedescribed relationship of the maximum attainable section lift coefficients and the actually prevailing section lift coefficients on the remainder of the semispan of the lifting surface outside of the "stall-inception panel" proper.

If, in any of the aforedescribed cases, the lifting surface under consideration is modified by excrescences such as, for example, power-plant nacelles, or flaps that modify the local zero-lift angle and the local maximum attainable section lift coefficient, the calculation of the spanwise distribution of the effective washout and the maximum attainable section lift coefficients takes due account of the effects of these modifications by introducing "equivalent values" of the effective washout and section mean-line camber into the subject method of this invention.

Upon completion of the procedure outlined for the subject method of this invention, the zero-lift angles of the fluid-foil sections selected thusly are determined for their respective mean-line cambers, thickness ratios, and Reynolds numbers, and each fluid-foil section is set properly with respect to the reference chord plane of the lifting surface, so that the desired effective washout is achieved.

By practicing my invention a lifting surface can be designed and constructed to achieve the objects heretofore stated.

Numerous flight tests and wind-tunnel tests in reputable wind-tunnels such as the California Institute of Technology, the Massachusetts Institute of Technology, the various wind tunnels of the National Advisory Committee for Aeronautics, and elsewhere have demonstrated convincingly that each of the objects of this invention has been fully achieved. The tests were performed on numerous wing models, on sailplanes, and on models of at least five aircraft designs of widely varying design scope employing a wide variety of airfoil series. Force-test records, photographic records, and cinematographic records of the tests substantiate the attainment of the objects of this invention.

The inventor wishes it to be clearly understood that the greatly improved and generally judged satisfactory stalling characteristics of the wings (and other lifting surfaces) designed and constructed according to the subject method of this invention are directly attributable to the use of three (or more) controlled fluid-foil sections selected according to the hereinbefore specified method of this invention, and to the aforedescribed method employed in the design of such lifting surfaces.

This invention accomplishes an important improvement in the art, and the discoveries herein disclosed are of great value to all types of aircraft (as well as to craft operating in other fluids), throughout their entire operating range, and especially in the critical low-speed operation where steadiness of lift and lift variation, stability of the craft, control effectiveness, and smoothness and stability of control forces are of vital importance for the safety and efficiency of the craft; also in violent maneuvers at high speeds when high lifting-surface lift coefficients comparable with those occurring at the low-speed stall are encountered and even temporarily surpassed.

I claim:

1 A lifting surface with three or more controlled fluid-foil sections, in which the first section with the smallest mean-line camber is located at the root, the second section with the greatest mean-line camber is located at the fluid-dynamically effective tip, and the third or additional fluid-foil sections are located at stations interjacent between the root and the tip, wherein the values of the mean-line camber of the interjacent fluid-foil sections are greater than the values of the mean-line camber obtainable at the respective spanwise stations by means of straight-line fairing between the fluid-foil section located at the root of the lifting surface and the fluid-foil section located at the tip of the lifting surface.

2. A lifting surface with three or more controlled fluid-foil sections, in which the first section with the smallest mean-line camber is located at the root, the second section with the greatest mean-line camber is located at the fluid-

dynamically effective tip, and the third or additional fluid-foil sections are located at stations interjacent between the root and the tip, wherein the values of the mean-line camber of the interjacent fluid-foil sections are at variance with the values of the mean-line camber obtainable at the respective spanwise stations by means of straight-line fairing between the fluid-foil section located at the root of the lifting surface and the fluid-foil section located at the tip of the lifting surface, said three or more controlled fluid-foil sections having values of the mean-line camber selected in such manner that the resulting spanwise distribution of maximum attainable section lift coefficients of the three or more controlled sections forms a curvilinear polygon enveloping a curve representing the spanwise distribution of section lift coefficients for a given planform actually prevailing at the maximum attainable lift coefficient of the lifting surface.

3. A lifting surface with three or more controlled fluid-foil sections, adapted to provide stall inception within a predetermined interval of spanwise stations in which the first section with the smallest mean-line camber is located at the root, the second section with the greatest mean-line camber is located at the fluid-dynamically effective tip, and the third or additional fluid-foil sections are located at stations interjacent between the root and the tip, wherein the values of the mean-line camber of the interjacent fluid-foil sections are at variance with the values of the mean-line camber obtainable at the respective spanwise stations by means of straight-line fairing between the fluid-foil section located at the root of the lifting surface and the fluid-foil section located at the tip of the lifting surface, said three or more controlled fluid-foil sections hav-

ing values of the mean-line camber selected in such manner that the resulting spanwise distribution of maximum attainable section lift coefficients of the three or more controlled sections forms a curvilinear polygon enveloping a curve representing the spanwise distribution of section lift coefficients actually prevailing at the maximum attainable lift coefficient of the lifting surface, and that the said resulting spanwise distribution of maximum attainable section lift coefficients for a given planform be so shaped that the first intersection with the spanwise distribution of actually prevailing section lift coefficients occurs in that interval of spanwise stations for which stall inception is to be obtained.

4. A lifting surface with three or more controlled fluid-foil sections, in which the first section with the smallest mean-line camber and greatest thickness ratio is located at the root, the second section with the greatest mean-line camber and smallest thickness ratio is located at the fluid-dynamically effective tip, and the third or additional fluid-foil sections are located at stations interjacent between the root and the tip, wherein the values of the thickness ratio of the interjacent fluid-foil sections are greater than the values of the thickness ratio obtainable at the respective spanwise stations by means of straight-line fairing between the fluid-foil section located at the root of the lifting surface and the fluid-foil section located at the tip of the lifting surface.

5. A lifting surface with three or more controlled fluid-foil sections, in which the first section with the smallest mean-line camber and greatest thickness ratio is located at the root, the second section with the greatest mean-line camber and smallest thickness ratio is located at the fluid-dynamically effective tip, and the third or additional fluid-foil sections are located at stations interjacent between the root and the tip, wherein the values of the thickness ratio of the interjacent fluid-foil sections are at variance with the values of the thickness ratio obtainable at the respective spanwise stations by means of straight-line fairing between the fluid-foil section located at the root of the lifting surface and the fluid-foil section located at the tip of the lifting surface, said three or more controlled fluid-foil sections having values of the thickness ratio selected in such manner that the resulting spanwise distribution of maximum attainable section lift coefficients of the three or more controlled sections forms a curvilinear polygon enveloping a curve representing the spanwise distribution of section lift coefficients for a given planform actually prevailing at the maximum attainable lift coefficient of the lifting surface.

6. A lifting surface with three or more controlled fluid-foil sections adapted to provide stall inception within a predetermined interval of spanwise stations, in which the first section with the smallest mean-line camber and greatest thickness ratio is located at the root, the second section with the greatest mean-line camber and smallest thickness ratio is located at the fluid-dynamically effective tip, and the third or additional fluid-foil sections are located at stations interjacent between the root and the tip, wherein the values of the thickness ratio of the interjacent fluid-foil sections are at variance with the values of the thickness ratio obtainable at the respective spanwise stations by means of straight-line fairing between the fluid-foil section located at the root of the lifting surface and the fluid-

foil section located at the tip of the lifting surface, said three or more controlled fluid-foil sections having values of the thickness ratio selected in such manner that the resulting spanwise distribution of maximum attainable section lift coefficients of the three or more controlled sections forms a curvilinear polygon enveloping a curve representing the spanwise distribution of section lift coefficients actually prevailing at the maximum attainable lift coefficient of the lifting surface, and that the said resulting spanwise distribution of maximum attainable section lift coefficients for a given planform be so shaped that the first intersection with the spanwise distribution of actually prevailing section lift coefficients occurs in that interval of spanwise stations for which stall inception is to be obtained.

7. A lifting surface with three or more controlled fluid-foil sections, in which the first section with the smallest mean-line camber is located at the root, the second section with the greatest mean-line camber is located at the fluid-dynamically effective tip, and one of the interjacent fluid-foil sections is located near a spanwise point where a tangent to the inboard portion of a curve representing the spanwise distribution of actually prevailing section lift coefficients for a given planform intersects a substantially horizontal tangent to the highest point of the same curve, wherein the values of the mean-line camber of the interjacent fluid-foil sections are greater than the values of the mean-line camber obtainable at the respective spanwise stations by means of straight-line fairing between the fluid-foil section located at the root of the lifting surface and the fluid-foil section located at the tip of the lifting surface.

8. A lifting surface with three or more controlled fluid-foil sections, in which the first section with the smallest mean-line camber and greatest thickness ratio is located at the root, the second section with the greatest mean-like camber and smallest thickness ratio is located at the fluid-dynamically effective tip, and one of the interjacent fluid-foil sections is located near a spanwise point where a tangent to the inboard portion of a curve representing the spanwise distribution of actually prevailing section lift coefficients for a given planform intersects a substantially horizontal tangent to the highest point of the same curve, wherein the values of the thickness ratio of the interjacent fluid-foil sections are greater than the values of the thickness ratio obtainable at the respective spanwise stations by means of straight-line fairing between the fluid-foil section located at the root of the lifting surface and the fluid-foil section located at the tip of the lifting surface.

9. A lifting surface with three or more controlled fluid-foil sections and having a highest actually prevailing section lift coefficient at a predetermined spanwise station, in which the first section with the smallest mean-line camber and greatest thickness ratio is located at the root, the second section with the greatest mean-line camber and smallest thickness ratio is located at the fluid-dynamically effective tip, and the third or additional fluid-foil sections are located at stations interjacent between the root and the tip, wherein the values of the mean-line camber of the interjacent fluid-foil sections are at variance with the values of the mean-line camber obtainable at the respective spanwise stations by means of straight-line fairing between the fluid-foil section located at the root of the lifting surface and

the fluid-foil section located at the tip of the lifting surface, and wherein the aforesaid fluid-foil section at the tip of the lifting surface has a thickness ratio smaller than the optimum thickness ratio for absolutely maximum attainable section lift coefficient of the fluid-foil series employed, so that a fluid-foil section having the optimum thickness ratio obtained by conventional interpolation between two of the controlled sections lies a short distance inboard of the tip of the lifting surface, near the spanwise station at which the highest actually prevailing section lift coefficient occurs.

10. A lifting surface with three or more controlled fluid-foil sections and having a highest actually prevailing section lift coefficient at a predetermined spanwise station, in which the first section with the smallest mean-like camber and greatest thickness ratio is located at the root, the second section with the greatest mean-line camber and smallest thickness ratio is located at the fluid-dynamically effective tip, and third or additional fluid-foil sections are located at stations interjacent between the root and the tip, wherein the values of the thickness ratio of the interjacent fluid-foil sections are greater than the values of the thickness ratio obtainable at the respective spanwise stations by means of straight-line fairing between the fluid-foil section located at the root of the lifting surface and the fluid-foil section located at the tip of the lifting surface, and wherein the aforesaid fluid-foil section at the tip of the lifting surface has a thickness ratio smaller than the optimum thickness ratio for absolutely maximum attainable section lift coefficient of the fluid-foil series employed, so that a fluid-foil section having the optimum

thickness ratio obtained by conventional interpolation between two of the controlled sections lies a short distance inboard of the tip of the lifting surface, near the spanwise station at which the highest actually prevailing section lift coefficient occurs.

11. A lifting surface with three or more controlled fluid-foil sections, in which the first section with the smallest mean-line camber is located at the root, the second section with the greatest mean-line camber is located at the fluid-dynamically effective tip, and the third or additional fluid-foil sections are located at stations interjacent between the root and the tip, wherein the values of the mean-line camber of the interjacent fluid-foil sections are smaller than the values of the mean-line camber obtainable at the respective spanwise stations by means of straight-line fairing between the fluid-foil section located at the root of the lifting surface and the fluid-foil section located at the tip of the lifting surface.

12. A lifting surface with three or more controlled fluid-foil sections, in which the first section with the smallest mean-line camber and greatest thickness ratio is located at the root, the second section with the greatest mean-line camber and smallest thickness ratio is located at the fluid-dynamically effective tip, and the third or additional fluid-foil sections are located at stations interjacent between the root and the tip, wherein the values of the thickness ratio of the interjacent fluid-foil sections are smaller than the values of the thickness ratio obtainable at the respective spanwise stations by means of straight-line fairing between the fluid-foil section located at the root of the lifting surface and the fluid-foil section located at the tip of the lifting surface.

13. A lifting surface with three or more con-

trolled fluid-foil sections, in which the first section with the smallest mean-line camber is located at the root, the second section with the greatest mean-line camber is located at the fluid-dynamically effective tip, and one of the interjacent fluid-foil sections is located near a spanwise point where a tangent to the inboard portion of a curve representing the spanwise distribution of actually prevailing section lift coefficients for a given planform intersects a substantially horizontal tangent to the highest point of the same curve, wherein the values of the mean-line camber of the interjacent fluid-foil sections are smaller than the values of the mean-line camber obtainable at the respective spanwise stations by means of straight-line fairing between the fluid-foil section located at the root of the lifting surface and the fluid-foil section located at the tip of the lifting surface.

14. A lifting surface with three or more controlled fluid-foil sections, in which the first section with the smallest mean-line camber is located at the root, the second section with the greatest mean-line camber is located at the fluid-dynamically effective tip, and one of the interjacent fluid-foil sections is located near a spanwise point where a tangent to the inboard portion of a curve representing the spanwise distribution of actually prevailing section lift coefficients for a given planform intersects a substantially horizontal tangent to the highest point of the same curve, wherein the values of the thickness ratio of the interjacent fluid-foil sections are smaller than the values of the thickness ratio obtainable at the respective spanwise stations by means of straight-line fairing between the fluid-foil section located at the root of the lifting surface and the fluid-foil section located at the tip of the lifting surface.

15. A lifting surface with three or more con-

trolled fluid-foil sections and having a highest actually prevailing section lift coefficient at a predetermined spanwise station, in which the first section with the smallest mean-line camber is located at the root, the second section with the greatest mean-line camber is located at the fluid-dynamically effective tip, and the third or additional fluid-foil sections are located at stations interjacent between the root and the tip, wherein the values of the thickness ratio of the interjacent fluid-foil sections are smaller than the values of the thickness ratio obtainable at the respective spanwise stations by means of straight-line fairing between the fluid-foil section located at the root of the lifting surface and the fluid-foil section located at the tip of the lifting surface; and wherein the aforesaid fluid-foil section at the tip of the lifting surface has a thickness ratio smaller than the optimum thickness ratio for absolutely maximum attainable section lift coefficient of the fluid-foil series employed, so that a fluid-foil section having the optimum thickness ratio obtained by conventional interpolation between two of the controlled sections lies a short distance inboard of the tip of the lifting surface, near the spanwise station at which the highest actually prevailing section lift coefficient occurs.

MAURICE ADOLPH GARBELL.

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REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,547,644	Cronstedt	July 28, 1925
1,817,275	Soldenhoff	Aug. 4, 1931
1,839,349	Sigrist	Jan. 5, 1932
1,890,079	Focke	Dec. 6, 1932

PROOF OF SERVICE.

I, George B. White, attorney for Maurice A. Garbell, Inc., and the Garbell Research Foundation, Petitioners herein, and a member of the Bar of the Supreme Court of the United States, hereby certify that, on the 13th day of April 1977, I served copies of the foregoing Appendix D to the Petition for a Writ of Certiorari to the Supreme Court of the United States, as identified on the cover hereof, on the several parties thereto, as follows:

1. On The Boeing Company, Defendant, by mailing three copies in a duly addressed envelope, with first-class postage prepaid, to its attorneys,

PERKINS, COIE, STONE, OLSEN & WILLIAMS,
J. PAUL COIE,
1900 Washington Building,
Seattle, Washington, 98101.
(206) 682-8770

2. On the McDonnell-Douglas Corporation, Defendants, by mailing three copies in a duly addressed envelope, with first-class postage prepaid, to its attorneys,

LOUIS LIEBER, JR.,
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3000 Ocean Park Boulevard,
Santa Monica, California 90405.
(213) 399-931[illegible], Extension 4275.

3. On The Boeing Company and the McDonnell-Douglas Corporation, Defendants, by mailing three copies in a duly addressed envelope, with first-class postage prepaid, to their attorneys,

HAHN, CAZIER, THORNTON, HOEGH & LEFF,
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It is further certified that all parties required to be served have been served.

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